The Application of a Downscaled Economic Model for Sediment Management Projects in Ireland and The Netherlands

Harrington, J.[a], Wijdeveld, A. [b], Wensveen, M.[c], Hamilton A.[d], Lord R.[e], Torrance K.[e], Debuigne T. [f], Masson E. [g], Batel, B.[a]

[a] *Sustainable Infrastructure Research & Innovation Group, Munster Technological University, Cork, Ireland*
[b] *DELTARES, P.O. Box 177, 2600 MH Delft, Netherlands*
[c] *Port of Rotterdam, 3198 LK Europoort Rotterdam, Netherlands*
[d] *Scottish Canals, Canal House, Applecross St, Glasgow, G4 9SP, United Kingdom*
[e] *Department of Civil & Environmental Engineering, University of Strathclyde, Glasgow G1 1XJ, United Kingdom*
[f] *Ixsane, 23 Av. de la Créativité, 59650 Villeneuve-d'Ascq, Lille, France*
[g] *University of Lille, 42 Rue Paul Duez, 59000, Lille, France*

email: joe.harrington@mtu.ie

ABSTRACT: The management of dredged sediment is a challenge for Ports and is the focus of the EU NWE Interreg SURICATES Project which investigates aspects of sediment management. This paper focuses on a regionally downscaled economic model to assess impacts of sediment management options (including disposal, treatment and reuse) for dredged sediments. The model analyses the economic benefits associated with sediment use and specifically Gross Domestic Product (GDP) and jobs created and has been applied to sediment management projects across the SURICATES Partner Countries (Ireland, Scotland, France and the Netherlands) and the United Kingdom (excluding Scotland).

The model facilitates regional analysis of effects of sediment management projects on GDP and job creation. Methods for estimating economic induced impacts are based on industry specific Type I & Type II economic multipliers and coefficients, derived for the EU Interreg NWE SURICATES partner countries using Symmetric Input-Output Tables and application of the open Leontief model based on available economic data for the identified countries. The model has been validated against completed sediment management projects.

The model has been applied to sediment projects in Ireland (Maintenance dredging – Port of Fenit) and in the Netherlands (Dredged sediment reallocation – Port of Rotterdam) and estimates the direct contribution to GDP and direct jobs created and indirect and induced economic project impacts. The model provides valuable results into the benefits of sediment management projects.

More generally it allows impact analysis for economic aspects of sediment projects with potential to inform stakeholders.

KEY WORDS: Dredging, Sediment Management, Economic, Model, GDP, Jobs Created, Port of Fenit, Port of Rotterdam, Circular Economy

1 INTRODUCTION

This paper presents a regionally downscaled economic model developed to assess the impacts of the management of dredged sediments. The model provides an additional tool to support the sustainable use and management of dredged sediments which is an ongoing and major challenge for many ports, harbours and river authorities worldwide.

The process of dredging involves the removal of sediments from the aquatic environment, including port and harbours and is critical to providing navigable access to ports and waterways.

Sediment management approaches that may be practiced including disposal (at sea or on land) or beneficial use (engineering use, environmental enhancement or agricultural and product uses). These sediment management approaches are now focusing on increased beneficial use in the context of the Circular Economy and 'Working with Nature' solutions to the maximum extent practicable. Sediment management practice and challenges have been presented in an Irish context by, for example, by [1], [2], [3] and in a broader international context, for example, [4], [5] and [6].

The sediment management technique selected wlll depend on a range of factors including the sediment characteristics and contamination levels (if any), local site conditions, and national and international practice. These feasibility issues are generally dependent on a range of often inter-related technical, financial, environmental, legislative and societal factors with this paper focusing primarily on the regional economic aspects of dredge sediment management.

The downscaled economic model presented in this paper facilitates the regional analysis of the effect of a dredging project on Gross Domestic Product (GDP) and job creation. The economic model analyses the direct, indirect and induced effect on GDP along with the direct, indirect and induced jobs created. The economic effects were downscaled to a regional EU NUTS3 (EU Nomenclature of Territorial Units for Statistics - NUTS) level using Simple Location Quotients (SLQs) for a number of countries in North West Europe (the partner countries in the EU Interreg NWE SURICATES Project [7]). The model assesses the potential economic impact, accounting for costs and benefits, within the time period of the project. Longer-term economic benefits which may be derived from beneficial use projects are not included in the analysis and would require significant assumptions to

This is a peer reviewed, accepted author manuscript of the following research paper: Harrington, J., Wijdeveld, A., Wensveen, M., Hamilton, A., Lord, R., Torrance, K., Debuigne, T., Masson, E., & Batel, B. (2022). The application of a downscaled economic model for sediment management projects in Ireland and The Netherlands. Paper presented at Civil Engineering Research in Ireland 2022.

be made and such an analysis would be sensitive to the assumptions made and may not be sufficiently reliable or robust. Thus, the analysis presented in this paper is actually likely to underestimate the full longer-term economic benefits of dredge sediment management projects.

2 METHODS

2.1 Economic Modelling Framework

Project economic impacts can be developed based on multipliers derived from Symmetric Input-Output Tables (SIOT). For these tables the outputs of one industry sector correspond to the input of another industry allowing identification of the impact of activities within a sector(s) for an economy, at a national or regional level [8]. A multiplier index measuring the total effect of an increase in investment on employment or income can be generated with three types of multiplier effect; direct, indirect and induced. Direct effects refer to the impact on economic activity of the industry/development. Indirect effects refer to the impact arising from upstream or inter-sectoral linkages, such as the income or jobs accruing to suppliers. Induced effects are impacts arising from general household spending of those directly and indirectly employed by the industry/development. This approach is well established to model the economic impacts of developments [9], [10].

Figure 1 presents the overall modelling approach applied including the primary model inputs (including the Economic Impact Area, the project site, sediment characteristics and unit costs from an extensive unit cost database), the available sediment management options (the full logistical chain of project activity from dredge sediment generation through to ultimate placement or disposal) and the model outputs (direct, indirect and induced contributions to GDP and employment),

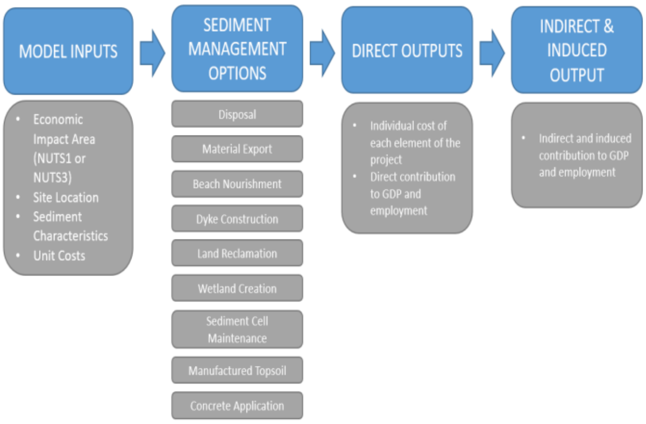

Figure 1. Overall Economic Model Structure – Inputs and Outputs

2.2 Direct Costs

The direct costs are the actual costs associated with completion of the project and it is the sum of all the individual process unit costs involved. The unit costs include essential processes of a dredging campaign such as design, environmental assessment, monitoring, dredging, sediment management, dewatering, treatment, transport, and any other relevant costs.

3 DIRECT, INDIRECT, AND INDUCED IMPACTS

The model generates the direct, indirect, and induced impacts in terms of the contribution to the Gross Domestic Product (GDP) and the resulting impact on jobs. GDP is the most common indicator of financial activity in a specific time period. It measures the total monetary value of all goods and services produced within country’s borders [11]. The expenditure approach, used in the economic model developed, estimates the direct impact on GDP by how much money is invested in the specific dredging project. The direct jobs created include those directly associated with the dredging project and any additional jobs created.

An increase in the final demand for a particular industry results in an increase in demand for other linked industries further down the supply chain. This is called the indirect contribution to GDP. The indirect contribution to GDP is estimated by applying sector specific Leontief Type I multipliers to the corresponding sectoral GDP. The direct cost of the individual elements is then deducted from this value [8]. The indirect employment represents the number of full-time equivalent jobs that are created as a result of the economic activity generated by the dredging project.

The induced contribution to GDP is the result of increased personal income caused by the direct and indirect effect on GDP, or in other words, the spending of employees. A proportion of this increased income will be re-spent and returned to the economy. The induced effect is estimated using the Leontief Type II Output Multipliers. Similar to Type I Output Multipliers, the Type II Output Multipliers are also derived from SIOT tables [8].

The relevant equations for direct, indirect and induced economic impacts at a National level have previously been presented in detail by [12] and [13].

4 DEVELOPED MODEL

4.1 National and Regional Economic Areas

The economic model was developed for five countries: Ireland, France, the Netherlands, Scotland, and the United Kingdom (excluding Scotland). The set of output multipliers and employment coefficients was derived for each country individually based on available data from national statistics offices, OECD, and Eurostat. Furthermore, the economic and employment contributions were downscaled to a regional NUTS3 level.

There are often considerable regional differences in terms of economic performance and these can be reflected through a downscaling approach to a regional NUTS3 level (Figure 2). The SLQ method (Equation 1) is a common estimation procedure quantifying how concentrated a particular industry is on a regional NUTS3 level relative to the reference NUTS1 level [11]. Eurostat provides employment data for eleven NACE (a statistical classification of economic activities in the EU) categories to a NUTS3 level. The NUTS3 employment data form an ‘asset’ to generate the SLQ ratios which are applied to the national level multiplier and employment coefficients. In the case where a region is over-represented as a proportion of employment in a particular sector, the national multiplier and employment coefficients were used for that region and where a region is under-represented the national multiplier was downscaled to reflect the degree of under-representation.

$$SLQ = (X/Y)/(X'/Y') \quad (1)$$

where

SLQ – Simple Location Quotient

X - Amount of asset in a region (sectoral employment)

Y - Total amount of comparable asset in a region (total employment)

X' - Amount of asset in a larger reference region (sectoral employment)

Y - Total amount of comparable asset in a larger reference region (total employment)

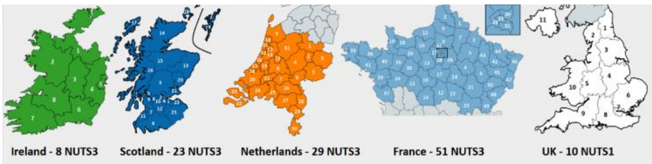

Figure 2. NUTS3 (& NUTS1) NWE Country Regions included in the Economic Model

4.2 *Unit Costs and Treatment Methods*

Unit costs were gathered from different dredging contractors and engineering consultants across the five countries identified. Treatment methods in the model include the most common applications that are widely used internationally. The economic model is flexible and allows customisation to satisfy various possible dredging scenarios.

5 MODEL APPLICATION

5.1 *Background*

The economic modelling tool developed has been validated against data from an actual dredging project. The validation involved comparing the model outputs with actual outputs in terms of the effect on GDP and jobs created. This validation exercise was initially presented for a Pilot Study Site where 533m^3 of sediment was dredged from a canal near Falkirk, Scotland and transported by road and placed at a bioremediation site. This Pilot Study formed part of the Interreg NWE SURICATES Project [7]. The validation exercise proved satisfactory with good comparison between real project data (direct cost and employment created) and the outputs from the economic model. A detailed description of the project site and the modelling work undertaken has previously been presented [13].

The model applications presented in this paper focus on two larger projects. One project is an innovative and large-scale sediment reallocation project within the Port of Rotterdam, The Netherlands, another Pilot Study as part of the Interreg NWE SURICATES Project. The second project is at a smaller scale and involves dredging and offshore disposal at the Port of Fenit, Co. Kerry, Ireland. In this case the sediment management approach implemented was assessed and compared with a number of other potentially feasible scenarios.

The following sections outline the modelling work undertaken.

5.2 *Sediment Reallocation, Port of Rotterdam*

The Port of Rotterdam in the Netherlands (Figure 3) is the largest seaport in Europe and a key asset in the international maritime supply chain. The Port has a large dredging requirement to maintain navigable access and it invests heavily in sediment management. As part of the EU NWE SURICATES Project the Port led a large-scale pilot project involving the dredging and reallocation of approximately 500,000m^3 of sediment. The overall aim of this pilot study was to assess the efficacy of sediment reallocation to support formation of wetland areas to provide erosion protection of channel banks and also to determine if such an approach could reduce the sailing distance of dredging equipment, thereby saving on CO_2 emissions.

The sediment was dredged by a Port-owned hydraulic dredger with an in-built hopper from the inner berthing areas of the Port (freshwater) and then reallocated approximately 10km downstream within a tidally controlled Port waterway area through a ‘rainbowing’ process, Figure 3 shows the dredged and sediment reallocation areas. The reallocation site (Figure 4) was selected based on numerical modelling work undertaken to mimic the behaviour and transport of the dredged sediments; this modelling work indicated a potential zone of sediment deposition.

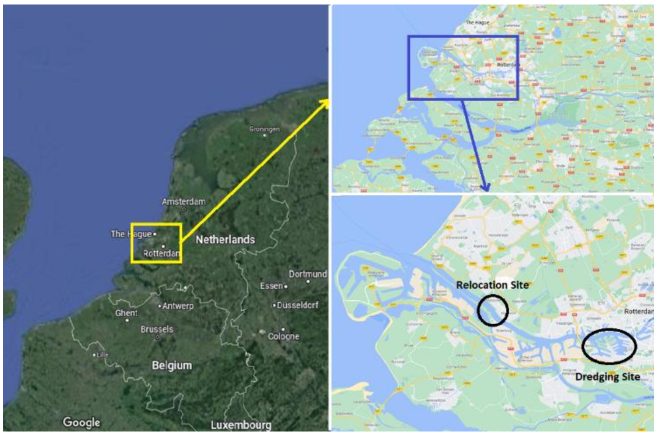

Figure 3. Port of Rotterdam Site Location

Figure 4. Hydraulic Dredger *Ecodelta* at the Reallocation Site

Deltares provided all the necessary information required to apply the economic model. This included the following project inputs: the type of dredging operation, beneficial use type and methods along with the outputs such as direct cost breakdown and total jobs created from the dredging project.

The economic model was applied to this sediment reallocation project. The actual cost of the dredging project was estimated at approximately €1million with 8 fulltime equivalent jobs created. The economic model was then applied and the impact on GDP and jobs created is presented in Figures 5 and 6, respectively. The economic model estimated a direct cost of €1.2m, which is approximately 20% higher than the actual direct cost of the dredging project. As this project involved the use of the Port-owned dredger the actual cost is likely to have been lower than if an external dredging contractor was used. The economic model estimated that the sediment allocation project would create 10.2 direct jobs. The comparison of such model output to actual project data is the first application for a large-scale project with differences of approximately 20% found, albeit with the mitigating proviso outlined above. The model predictions indicate the indirect and induced contributions to GDP (as a proportion of the direct contribution) at 56% and 5.1% respectively.

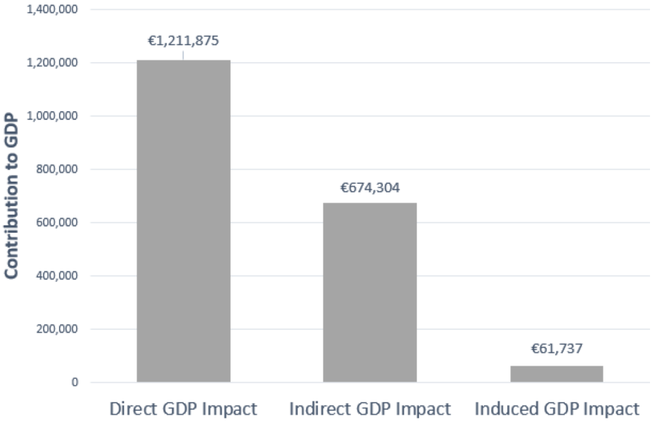

Figure 5. Sediment Reallocation Project – Modelled Effect on GDP

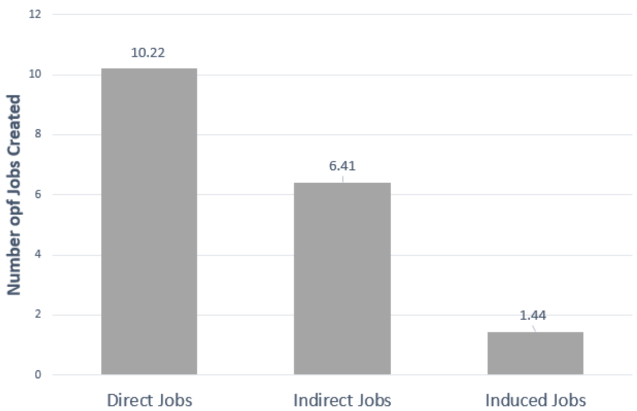

Figure 6. Sediment Reallocation Project – Modelled Number of Jobs Created

5.3 Sediment Management, Port of Fenit

Fenit Harbour is a mixed function seaport under the auspices of Kerry County Council. It the most westerly commercial port in Ireland and is located on the northern part of Tralee Bay (Figure 7). Maintenance dredging is an ongoing requirement to provide safe navigable access and berthage for commercial shipping and recreational craft.

Current harbour planning envisages dredging of approximately 1m tonnes of dredged sediment over the coming 8-year period with an initial phase of dredging completed in May 2021 when dredging was undertaken for 57,770 m^3 with offshore disposal to an EPA licensed site 7km sail distance. The dredging was undertaken by an external dredging contractor as a combination of primarily suction hopper dredger with some plough dredger activity (Figure 8).

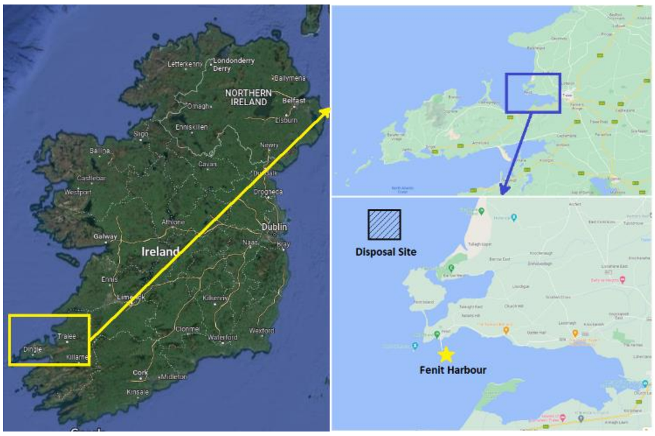

Figure 7. Port of Fenit Site Location

Figure 8. Hydraulic Dredger *Marbury* (left) and Plough Dredger (right) used at the Port of Fenit

The economic model was applied to assess a number of sediment management scenarios based on the dredging volume for the May 2021 dredging campaign as follows:

(1) The completed works of dredging and offshore disposal, (2) Construction of a flood protection dyke using dredged sediments and (3) Wetland restoration.

The flood protection dyke is proposed to be located on a coastal stretch approximately 7.6km from the Port dredging site where there is a high probability of flooding (Figure 9) based on predictions by the Irish Office of Public Works. It is assumed that all 57,770 m^3 of fine dredge sediment would be reused for the construction of the 2.1km long dyke with a dyke height of 3m and crest width of 2.5m, a geotextile filter layer and a rock armour outer layer requiring 6,000 m^3 of rock material supplied by the nearby Ardfert Quarry, a trucking distance of approximately 11km from the dyke construction site. It is assumed for purposes of this modelling work that the dredged sediment is suitable for such an application.

Figure 9. Proposed Dyke Location and Areas of High Flood Risk in Tralee Bay

Wetlands have a valuable and beneficial role in flood regulation, water purification and wildlife habitat and Tralee Bay is an internationally important wetland for wintering waders and wildfowl. Local wetland habitats include swamps, tidal marshes, peatlands and inter-tidal areas. The fine dredged sediment from the Port of Fenit is potentially suitable for nourishing and enhancing the existing Tralee Bay wetlands which are located approximately 2.5km sail distance from the Port of Fenit. It is a large wetland area covering 314 hectares and contains estuarine silts and clays (Figure 10).

The wetland restoration scenario involves the 57,770 m^3 of silty dredged sediment being transported via trailer suction dredger and placed into the designated wetland area via high-pressure discharge of dredged sediment. The thickness of the applied sediment layer is generally lower in the vegetated areas and higher in the open water areas. No berm or weir box installation is required. It is assumed for modelling purposes that the dredged sediment is appropriate for such use. This sediment application would of course require extensive site investigation, sampling and environmental assessment.

Figure 10. Identified Wetland Areas in Tralee Bay

The economic model was applied to the three sediment management scenarios, either implemented or proposed. Figure 11 presents the results of the model application for the different scenarios.

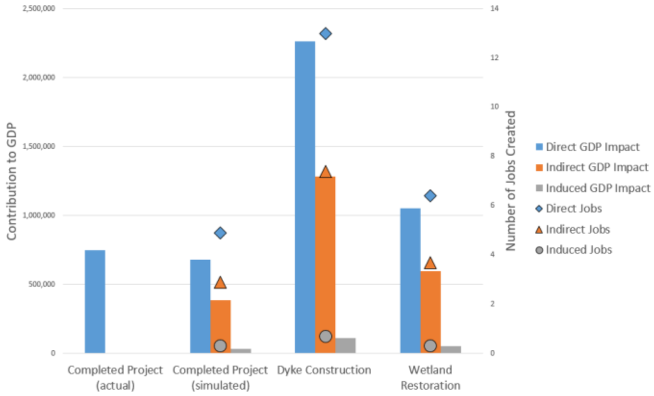

Figure 11. Port of Fenit Sediment Management Scenarios – Economic Modelling Results

The actual cost of the dredging and offshore disposal (completed project) was estimated at approximately €750k, no estimate of employment created by the project was available. The economic model estimated the direct cost at €681k, a difference of less than 10% which is considered satisfactory. The model predicts indirect and induced contributions to GDP of €385k and €34,600, 56% and 5% respectively of the direct GDP contribution. The model predicted direct, indirect and induced employment at 5, 3 and 0.3 Full Time Equivalent (FTE) jobs.

The application of the economic model to the different sediment management scenarios shows that the lowest direct cost approach is the offshore disposal option, confirming current practice and experience in Ireland. The positive economic impact is largest for the dyke construction scenario and the wetland restoration proposal also provides a greater economic benefit than disposal at sea.

The model predicts the contribution to GDP from dyke construction at approximately €2.3m, with indirect and induced contributions of approximately €1.3m and €113k respectively (56% and 4.9% of direct GDP contribution respectively). The estimated number of jobs created was 13FTE. Similarly, for wetland restoration the model predicts the contribution to GDP at approximately €1.05m, with indirect and induced contributions of approximately €597k and €53k respectively (57% and 5% of direct GDP contribution respectively). The direct number of jobs created was estimated at 6.4FTE.

These model estimates indicate the positive potential economic benefits that may be derived from sediment use projects, rather than the application of more traditional disposal at sea. This is in addition to a range of other non-economic benefits that can be achieved through such beneficial use applications.

6 CONCLUSION

This paper presents a regionally downscaled economic model that has been developed and can analyse, through the contribution to GDP and jobs created, the economic impacts of sediment management projects. The economic model is based on applying an open Leontief model to standardised symmetrical input-output tables based on national and regional statistical economic data. The model numerically outputs the direct, indirect, and induced effect of GDP and jobs created.

The model has been applied to two sediment management projects; a large-scale sediment reallocation project at the Port of Rotterdam, The Netherlands and a smaller scale dredging project at the Port of Fenit, Ireland. Model predictions for the direct economic impacts for the Port of Rotterdam Project are within 20% of the estimated actual project values (but with the mitigating proviso regarding the likely reduced cost by the use of the Port-owned dredger). For the Port of Fenit project the model provides a satisfactory prediction of the actual cost of the dredging and offshore disposal project, within 10% of the actual cost. For both projects the indirect contribution to GDP has been found to be over 50% of the direct contribution which is considerable; the induced contribution is much smaller and estimated at approximately 5%.

A number of different sediment management scenarios are also modelled for the Port of Fenit project including dyke construction and wetland restoration. This modelling work shows that the traditional practice of offshore disposal provides the lowest direct cost and that the beneficial use scenarios provide greater positive economic impact. A range of other benefits will also be derived from the beneficial use of sediment (which may include environmental, ecological, CO_2 emission reduction, flood protection, societal and/or recreational). In the context of these potential benefits, the Circular Economy and the philosophy of 'Working with Nature' this economic modelling work provides further evidence to support the increased beneficial use of sediment.

The economic model developed is unique with application at a National and a Regional level. It has been applied in this paper to real dredge sediment management projects in Ireland and the Netherlands and highlights the positive economic impact of sediment projects. The model can facilitate and inform stakeholders across the sector but it is important to note that the model results must be considered in the context of broader environmental and societal impacts and industry needs.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the funding received for the SURICATES Project through the INTERREG NWE programme and the European Regional Development Fund (ERDF).

The authors would like to thank the Irish Central Statistics Office, the United Kingdom Office for National Statistics, the Scottish Government's National Statistics Office, The Organisation for Economic Co-operation and Development (OECD), and Eurostat who provided economic data.

The authors would like to thank to Dr. Declan Jordan from University College Cork for advice and guidance.

The authors also wish to thank the other SURICATES project partners (Université de Lille Sciences et Technologies, France; IXSANE, France; Bureau de Recherches Géologiques et Minières, France; TEAM2, France; ARMINES, France; Deltares, The Netherlands; Port of Rotterdam, The Netherlands; University of Strathclyde, Scotland; Scottish Canals, Scotland; University College Cork, Ireland) for the provision of data and advice as appropriate.

REFERENCES

[1] Harrington, J., Sutton, S., Lewis, A. (2004). "Dredging and dredge disposal and reuse in Ireland – a small island perspective", Proceedings of World Dredging Congress XVII, B4-5, 1-14, Hamburg, Germany.

[2] Sheehan, C., Harrington, J., **(**2012**)** 'Management of dredge material in Ireland – a review'. Waste Management, Volume 32, Issue 5, Pages 1031-1044. https://doi.org/doi.org/10.1016/j.wasman.2011.11.014

[3] Harrington, J. and Smith, G. (2013). Guidance on the beneficial use of dredge material in Ireland, Environmental Protection Agency.

[4] Bortone, G., Palumbo, L., **(**2007**).** SedNet: Sustainable management of sediment resources - sediment and dredged material treatment. Elsevier, The Netherlands.

[5] Laboyrie, H.P.,, Van Koningsveld, M., Aarninkhor, S.G.J., Van Parys, M., Lee, M., Jensen, A., Csiti, A., Kolman, R., **(**2018**).** Dredging for sustainable infrastructure. CEDA/IADC, The Hague, the Netherlands.

[6] United States Army Corps of Engineers **(**2013**)** Dredging and dredged material management - engineering manual. Engineering Manual EM 1110-2-5025, Department of the Army, Washington DC, USA.

[7] SURICATES - Sediment Uses as Resources In Circular And Territorial EconomieS (2022). https://www.nweurope.eu/projects/project-search/suricates-sediment-uses-as-resources-in-circular-and-territorial-economies/. Accessed 5 May 2022.

[8] Leontief, W., (1951). Input output economics, Scientific American, 1951. 185, pp. 15-21.

[9] Hawdon, D. Pearson, P. (1995). Input-output simulations of energy, environment, economy interactions in the UK, Energy Economics, (1995) 17(1): p. 73-86.

[10] Ivanova, G., Rolfe, J. (2011). Using input-output analysis to estimate the impact of a coal industry expansion on regional and local economies, Impact Assessment and Project Appraisal, (2011). Beech Tree Publishing 29(4): p. 277-288.

[11] Carey, M.A., Johnson T.G., (2014), 'Ireland's Input-Output Framework – Where Are the Regions?', *Borderlands*, Issue 4.

[12] Harrington, J. R., Murphy, J., Coleman, M., Jordan, D., Debuigne, T. and Szacsuri, G. (2016) 'Economic modelling of the management of dredged marine sediments', Geology, Geophysics and Environment, 42(3), pp.311-324. doi: 10.7494/geol.2016.42.3.311.

[13] O' Sullivan R., Harrington, J., Hamilton, A., Batel, B., 'The Application of an Economic Modelling and Analysis Tool to Assess the Economic Benefits and Impacts of Beneficial Use of Dredged Sediment'; Civil Engineering Research Ireland (CERI) Conference, pp. 630-634, Cork Institute of Technology (Online), August 2020, ISBN 978-0-9573957-4-9.